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MANAGING THE INTRODUCTION OF NEW PROCESS TECHNOLOGY: AN INTERNATIONAL COMPARISON

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WP#3004-89-BPS March, 1989

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ABSTRACT

This paper examines the introduction of new technologies in the manufacturing environment. It presents results of a study of new equipment introductions in eight manufacturing plants in Italy, West Germany, and the United States. Drawing on both quantitative and qualitative data on 48 introduction projects, the paper examines variations in performance and identifies managerial factors which may account for these differences.

In order to understand the requirements of process change, two relevant dimensions of technological change are identified. These are "technical complexity", which relates to the number and novelty of new technical features, and "systemic change", which relates to the degree of change in basic concepts or approaches to production. Further, three groups of organizational response mechanisms are identified. These are preparatory (or early) search, joint search with experts external to the plant, and functional overlap within the project team.

Two indicators of project success are examined. They are elapsed time required to complete the project, and operating improvement attributable to the new technology. Comparing success across regions, both startup time and operating improvement are, on average, statistically indistinguishable in Germany and Italy. However, performance on both dimensions is significantly worse in the U.S.

This performance gap is explained by differences in the intensity with which the three response mechanisms are used across regions. In order to understand the source of these differences, the paper examines historical and organizational differences among plants in the three regions. It is apparent that managerial choices over time have resulted in distinct sets of organizational capabilities, resources, and assumptions which may affect the way different plants approach technological problem solving.

INTRODUCTION: NEW PROCESS TECHNOLOGY -- PROMISES AND PROBLEMS

Example: The Case of Factory Q

In December of 1982, Factory Q installed a new, high-precision machining line which promised to move the factory into the modern age of metal working. The line would be the first integrated, continuous operation in Factory Y; according to management the technology represented the future of the company, and of manufacturing in general.

In December, 1986, the author walked through the line with one of the process engineers who had worked on debugging the process. The line was in operation, but was not yet operating at full capacity on a consistent basis. Efficiency was still below acceptable levels. Product quality was passable, but no one was sure how the new line's quality performance should be assessed because engineers had never found time to install and learn to use new measuring equipment as originally planned.

Personnel were quick to note that the line represented a significant step forward for the plant, and the project had been successful in ways that its efficiency ratings did not capture. Nonetheless, the experience had devastated the plant. For four years, the new line had drained engineering and maintenance resources from other parts of the plant. The best operating and technical personnel were still assigned full time to the new process. The line demanded continuing inputs of capital, and had not begun to pay back the sizable investment it represented. In the interim, corporate management had determined that Factory Q was probably not ready, after all, to become the high-performance, automated producer they had hoped it could be. The new line was designated to be removed, and the reality facing plant personnel was that the factory was likely to be closed.

The Challenge of Technological Changes

This case is repeated, often in less extreme form, too frequently in too many factories. When companies introduce new processes, the real failures are not those introductions which are quickly rejected by the organization, but those which create a persistent drain on human and capital resources without yielding competitive benefits. One major study found that productivity losses

associated with introducing new process equipment frequently equal or exceed the original cost of the equipment, and that the disruptive effects can persist for two years or more (Chew, 1985; Hayes and Clark, 1985). Persistent problems can have serious competitive implications as deliveries, reputation, and market share slip. Further process change becomes impossible, while competitors' process technologies move steadily ahead.

These concerns are particularly relevant in the United States. Jaikumar (1986), for instance, argues that indeed U. S. managers "are buying the hardware of flexible automation -- but they are using it very poorly. Rather than narrowing the competitive trade gap with Japan, the technology of automation is widening it further" (p. 69). Thurow (1987) blames "America's poor productivity, quality, and trade performance" squarely on inferior capabilities in introducing and using process technology. According to the Manufacturing Studies Board, U.S. companies need to "reemphasize process improvements -- selecting, using, and implementing available manufacturing technologies -- as a critical competitive weapon." (Manufacturing Studies Board, 1986; p. 17)

However, despite evidence of problems and their competitive implications, little is known about how managers can improve their organizations' ability to utilize new technology. Much of the existing research on process innovation and diffusion has focused on the decision to adopt new technology, rather than on the process of learning to use a new technology once it has been brought into the organization (Kimberly, 1981; Rogers, 1983). Some studies have examined the "implementation" stage of the diffusion-innovation process, however most of this research has focused on developing organizational attitudes and receptivity to change[1]. This is a useful first step, but it fails to illuminate the behaviors needed to identify and address the problems and uncertainties involved in technological process change.

The Need for Problem Solving at the Plant Level

The premise of the paper is that the success of a new process introduction is not just a function of organizational receptivity. Success is also dependent on managerial responses to technological change which facilitate adaptation of the new technology, the existing manufacturing system, and the

organization itself. The new technology may not fit with existing production processes, it may require new operating skills or procedures, or it may draw on novel areas of knowledge or new organizational linkages (Abernathy and Clark, 1985; Leonard-Barton, 1987; Van de Ven, 1976). Consequently, new process introductions often require considerable problem solving and even innovation at the plant level (Kazanjian and Drazin, 1986; Rice and Rogers, 1980).

At the same time, however, the organizational task associated with ongoing operations involves following standard procedures to produce products in a predictable, efficient, and accurate manner. Existing production processes and communication patterns serve this end by routinizing activity programs and preserving organizational roles and assumptions (Hedberg, Nystrom and Starbuck, 1976; March and Simon, 1958).

Integrating new technology into ongoing operations, therefore, requires the organization to respond to two different and frequently conflicting sets of demands (Abernathy, 1978; Maidique and Hayes, 1984; Van de Ven, 1986). This paper examines managerial responses to this dilemma. It explores several adaptive response mechanisms used by organizations, and analyzes their impact on the success of new introduction projects. Further, the paper examines some of the historical and organizational factors that may influence a project team's choice of response mechanisms, and that affect the team's ability to use those response mechanisms effectively for meeting the challenge of change.

The balance of the paper is organized in six parts. In Part I, I draw on existing literature to identify three critical organizational response mechanisms. Part II describes the research methodology and the variables used in the analysis. Part III discusses the research setting in terms of salient characteristics of operations in the different geographic regions studied. Part IV examines the data on project attributes and project success, and compares results across regions. Finally, in Part V, I discuss some of the forces which may explain the differential success of introduction projects in various regions, and in Part VI suggest some conclusions based on that analysis.

I. ORGANIZATIONAL RESPONSES TO TECHNOLOGICAL CHANGE

An organization's proactive efforts to deal with change can fall into one of two broad categories. First, the organization can prepare. By gathering information and making necessary adjustments early, before it undertakes the change, the organization decreases the uncertainty it faces and increases its ability to plan for or control events. Second, the organization can increase its ability to adapt to unexpected events once change has occurred. This involves developing ways to capture, transmit and use new information through increased coordination and feedback in "real time" (during task execution). Theorists argue that if the organization facing change increases neither preparatory efforts nor real time coordination and feedback, it has no choice but to accept a lower level of performance (Galbraith, 1973; March and Simon, 1958; Thompson, 1967).

Based on this dichotomy between preparatory planning and real-time coordination and feedback, I identified three organizational "response mechanisms" which managers use to deal with the challenge of process change in the ongoing factory. These are: 1) preparatory, or early, search undertaken before the new technology is put into use; 2) joint search during the startup process with technical experts outside the factory, and 3) functional overlap between engineering and manufacturing groups at the plant level. The first of these refers to preparatory efforts to identify potential problems and make appropriate adjustments before the technology is put in place. The second and third response categories both involve real-time mechanisms for adapting to problems and opportunities which develop as the organization gains experience with the new technology.

1. Preparatory Search: In the case of new process technology, increasing the factory's ability to preplan events requires that operating personnel not only investigate the new technology, but also modify or "reinvent" the new technology and relevant aspects of the receiving organization before the technology is installed in the factory (Rice and Rogers, 1980; Rogers, 1983; Van de Ven, 1986) This may involve adapting existing manufacturing systems, routines and procedures (Bright, 1958; Chew, 1985).

While researchers have argued in theory that early modification of both the existing system and the new technology is a critical part of the innovation

process (Rogers, 1980; Leonard-Barton, 1987), they have not distinguished empirically adjustments made in preparation for technological introductions from adjustments made in response to new technology once it is installed. Therefore, little is known about the effect of these early activities on the outcome of process change projects, or about the propensity of organizations to undertake preparatory search activities.

To the extent that the manufacturing organization cannot identify and address in advance all potential problems associated with the new technology, it will need to rely on mechanisms for real-time problem solving during the actual startup of the new process. Existing research suggests two important mechanisms for enabling real-time adaptation by increasing feedback and coordination across organizational boundaries.

2. Joint Search: One mechanism for responding in real time to process change is to increase the level of coordination with knowledgeable individuals from facilities or organizations external to the manufacturing plant. The notion of mutually productive problem solving across organizations stems from the concept of an "organization set" (Evan, 1966; Thompson, 1967) or, more specifically, a unit's "technological organization set". The latter can be defined as a coalition of suppliers of technology, equipment, components, or information from within and outside of the organization (Lynn, 1982). Lynn proposed that joint problem solving among members of the relevant technological organization set can account for "a major part of the company's problem solving capability with respect to the new technology" (page 8).

Studies in a variety of technological contexts have pointed to the importance of interaction with relevant members of the organization set, such as equipment vendors (Ettlie and Rubenstein, 1980; Leonard-Barton 1987) or component supplier networks (Imai, Nonaka and Takeuchi, 1985; Clark, 1988). However the importance of outside participation during the startup process seldom has been analyzed systematically.

3. Functional Overlap: Another means of increasing the factory's ability to adapt to technological change is to link relevant functions within the organization to create "overlapping" subsystems or multifunctional teams for

dealing with change (Gerwin, 1981; Landau, 1969). In the case of new process introductions, information about the actual performance of the new technology and its interaction with existing operations normally originates on the plant floor, whereas equipment and process modifications are typically specified within the plant technical or engineering function. At the same time, new technological information generally originates in the engineering area, whereas day-to-day decisions involving the use of the technology are made on the plant floor. Creating linkages between engineering and production moves the locus of decision-making closer to the source of relevant information, and therefore increases the organization's ability to respond to uncertainty on the plant floor (Beckman, 1986; Perrow, 1967).

As discussed above, fixed equipment, operating procedures, and communication channels tend to increase productive efficiency but to decrease the plant's adaptive capabilities. On the other hand, the three response mechanisms discussed here are expected to facilitate adaptation of the new technology, the existing manufacturing system, and the organization itself in the face of significant change in the production process.

II. RESEARCH METHODOLOGY

Methodology and Data Gathering

The introduction of new process technology into existing plants is a long and complex process. Progress may be affected by multiple, sometimes subtle factors related to the project and its context. Understanding these factors typically requires in-depth clinical analysis of individual cases. However, in order to identify patterns and systematic variations among projects, it is necessary to compress this complexity into a few standardized measures which can be compared across multiple observations. To meet these competing demands, I collected three kinds of data: descriptive information about projects, their history and contexts through open-ended and semi-structured interviews; specific information about project characteristics and outcomes through a written questionnaire; and archival information about plant operations and projects undertaken.

Early field work was clinical in nature and began with open-ended interviews of managers and technical staff at the corporate and division levels. This provided perspective on the company's competitive environment and manufacturing task, the technologies employed, and the impact of changes in these areas. Next, exploratory interviews at each plant were used to examine salient dimensions of the technological change process, and to identify new process introduction projects and principal informants.[1]

Data on each project were gathered through a series of semi-structured interviews with principal informants and other project participants, in conjunction with a written questionnaire. Interviews lasted from one to four hours. Managers at the plant and division levels were asked to corroborate information gathered from project participants. In addition, project documentation was used both directly by the researcher, and by respondents as an aid to answering factual questions in interviews and questionnaires.

This methodology was useful because it allowed interaction between the exploratory aspects of the research and the collection and analysis of the data. The opportunity to interview each respondent several times allowed measures to be refined in an iterative fashion. Because the study was conducted over the course of a year or more (depending on the project), it was possible to collect new evidence with which to refresh memories and to observe developments in those projects which were still ongoing (nine of 48 cases). New insights derived during the course of the research were used both to guide the analysis of the data collected, and to interpret results.

Site Selection

Research was undertaken at a single leading manufacturing company, and involved eight plants located in the United States, West Germany, and Italy. Limiting the research to one global corporation had several benefits,

[1] In each case the principal informant (also referred to as the "project manager") was identified during early field work as the person who had the "most direct, day-to-day responsibility for bringing the new technology up to speed in the factory". Other project participants were identified both by plant management and by principal informants.

including controlling for industry- and firm-related variations and facilitating access to detailed and confidential information about projects and their historical, technological, and competitive contexts (see Rogers, 1983; p. 361; Graham and Rosenthal, 1986).

The Company operates in a single, well-defined industry (precision metal components), and is the world market leader in its industry. Its sales are more than 50% greater than its closest competitor, and its reputation for product quality is unequalled. Competition in the industry focuses on consistent precision quality as well as cost, and senior managers view the Company's superior manufacturing capabilities as their primary competitive tool. These capabilities are supported by extensive in-house process development activities. New machine tools and manufacturing processes are developed at the central Process Development Laboratory and in several divisional technology centers.

The Company is organized geographically, and operations in individual countries are run as separate divisions with local management. This study was carried out in three major divisions within the Company -- West Germany, Italy, and the United States -- and involved two to three plants in each division. These eight plants represent a cross-section of the Company's operating facilities. They include one large factory in each division manufacturing a core part of the product line and often located close to the division offices and technology center. In addition, the sites chosen include more remote and specialized facilities such as subcomponent plants which serve as internal suppliers to other factories.

The fact that the research spanned multiple countries is significant. In particular, I anticipated that, even within the same company, managers in different countries might take different approaches to the introduction of new process technology (Jaikumar, 1986; Lynn, 1982; Clark, 1988). In fact, as the research progressed significant differences emerged among operations in different countries; these differences are discussed in Part III.

Sample Selection

The sample of projects studied includes of all the new process introductions identified where the technology was "new" in some way to a particular factory and which:

1) were undertaken during the last four years and completed or nearing completion at the time of the study;

2) represented a total capital investment of greater than $50,000 (in constant 1986 U.S. dollars); and

3) involved participants who were available for interview.

The sample includes a spectrum of technological process change, from incremental improvements over existing equipment to introductions of novel technologies and production systems. Production technologies include metal turning and precision machining equipment, assembly and inspection systems, thermal treatment and metal forming equipment, and handling systems. Four to eight projects were studied in each plant. A total of 48 introduction projects comprise the sample.

Variable Definition

In order to investigate organizational responses to process change and their impact on project success, quantitative measures were developed for each of the following:

(1) Project Attributes: The size and nature of the technological change involved, relative to existing technology and to past practice in the specific user environment;

(2) Response: The organization's response to the change, in terms of the three mechanisms identified in Part I;

(3) Outcome: The success of the introduction project, in terms of the disruption experienced and the benefits gained.

Variables are described below; details on the measurement process, including questionnaire and interview items, are available from the author.

Project Attributes

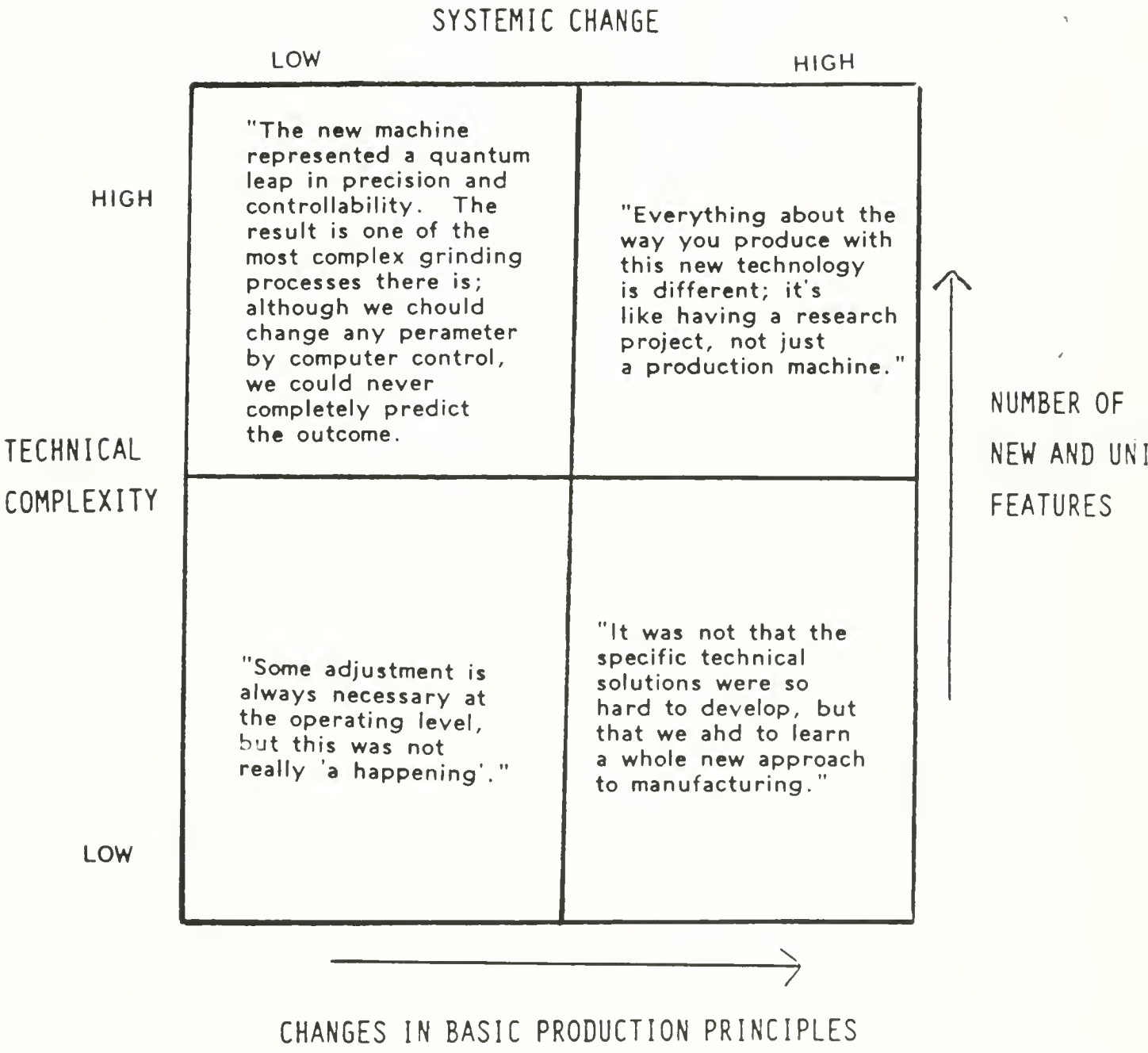
Twenty four separate questionnaire and interview items asked respondents to rate the newness of the technology and the nature of the change it represented in the plant environment. The original items were then reduced to six aggregate scales of technological change, which increased their statistical reliability and interpretability as measures of technological change. Scale reliabilities ranged from adequate (Cronbach's alpha=.64) to very high (Cronbach's alpha=.86). Finally, aggregate scales served as input for exploratory factor analysis to identify underlying dimensions of process change. The factor procedure employed principal analysis with verimax rotation and orthogonal factors (Jackson, 1983; p. 147).

Analysis revealed convergence around two factors, accounting for 53% of the variance in the aggregate scales of technological change. The first factor, labeled technical complexity, measures the number and novelty of new features introduced (such as tooling; measurement and control systems). The second factor, called systemic change, is the degree to which the new equipment or system introduces basic manufacturing concepts or operating principles which are new to the plant.

These two aspects of process change are orthogonal by construction; a given project may be technically complex yet entail a very low level of systemic change, or vice-versa. When both technical complexity and systemic change are high, the introduction represents a "radical" shift in the technology of the factory. The practical meaning of this distinction is illustrated by managers' comments about projects which were rated particularly high or low on these variables, as shown in Figure 1.

Figure 1

Two Aspects of Technological Process Change


SYSTEMIC CHANGE
LOW
HIGH
HIGH
TECHNICAL
COMPLEXITY
LOW
"The new machine represented a quantum leap in precision and controllability. The result is one of the most complex grinding processes there is; although we chould change any perameter by computer control, we could never completely predict the outcome.
"Everything about the way you produce with this new technology is different; it's like having a research project, not just a production machine."
"Some adjustment is always necessary at the operating level, but this was not really 'a happening'."
"It was not that the specific technical solutions were so hard to develop, but that we ahd to learn a whole new approach to manufacturing."
NUMBER OF
NEW AND UNI
FEATURES
CHANGES IN BASIC PRODUCTION PRINCIPLES

Although derived from the data, these two aspects of technological change are grounded in existing theories of technology and innovation. In particular, they build on Perrow's (1967) model of variety and analyzability in a production process, and on Abernathy and Clark's (1985) distinction between innovations which build on existing firm capabilities, and innovations which disrupt or obsolete existing competencies.

The scale of the introduction project, regardless of its technological content, is also considered an important attribute of the project (Chew, 1985). Scale is measured in terms of the total investment in new equipment, tooling, and other capitalized items (converted to constant 1986 U.S. dollars).

The Organization's Response to Change

1. Preparatory search: The intensity of search and adjustment undertaken before installation of the new process was measured in interview and questionnaire items detailing (1) the involvement of factory personnel in proposing and developing the technical features of the new equipment or system, and (2) development and testing activities carried out by factory personnel prior to the delivery or installation of the new technology. Four items comprised an aggregate scale with adequate reliability (Cronbach's alpha = .67).

2. Joint Search: Measures of the intensity of joint search are based on participants' descriptions of the role of personnel from outside of the factory, including the rated importance of contributions made by outsiders during the start-up process. Four interview and questionnaire items formed the aggregate scale (Cronbach's alpha .79).

3. Functional overlap: Functional overlap is defined as the degree to which the roles of plant engineering and production personnel were merged within the introduction project. Overlap was measured by the number of lateral linkages used in the project. Eight possible forms of lateral linkages were identified. Since linkages are adopted cumulatively (Galbraith, 1973), a higher score represents a greater number of linkages and a greater intensity of integration between functions. Primary information came from (1) participants'

sketches of the "people and project structure" on the written questionnaire and (2) participants' descriptions of the involvement and contribution of various players in the problem solving process.

Project Outcome

Multiple measures of project outcome were investigated; two principal measures are discussed in this paper.

1. Startup Time: The elapsed time between installation and productive use of new process technologies has important economic and competitive implications for the firm (Chew, 1985; Gunn, 1987; Thurow, 1987), and proved to be of overwhelming importance to managers in this study. Startup time influences factory efficiency and delivery performance, the ability to carry out other projects, and career growth of project participants. Startup time is defined as the sum of:

1) **Initial startup period**: the elapsed time in months from delivery of the equipment until parts are being made in production mode; plus

2) **Introduction period**: the elapsed time in months from delivery until the new process operates smoothly at acceptable levels of output, cost, and quality.[2]

This definition of startup time incorporates the notion that the initial startup period, during which disruption to ongoing operations is often significant, is generally far more costly (in both resources used and opportunities foregone) than the later period, when the technology is operating productively but is not yet fully debugged. Information came from project schedules and key dates reported on the written questionnaire, with corroboration from project documentation and plant management.

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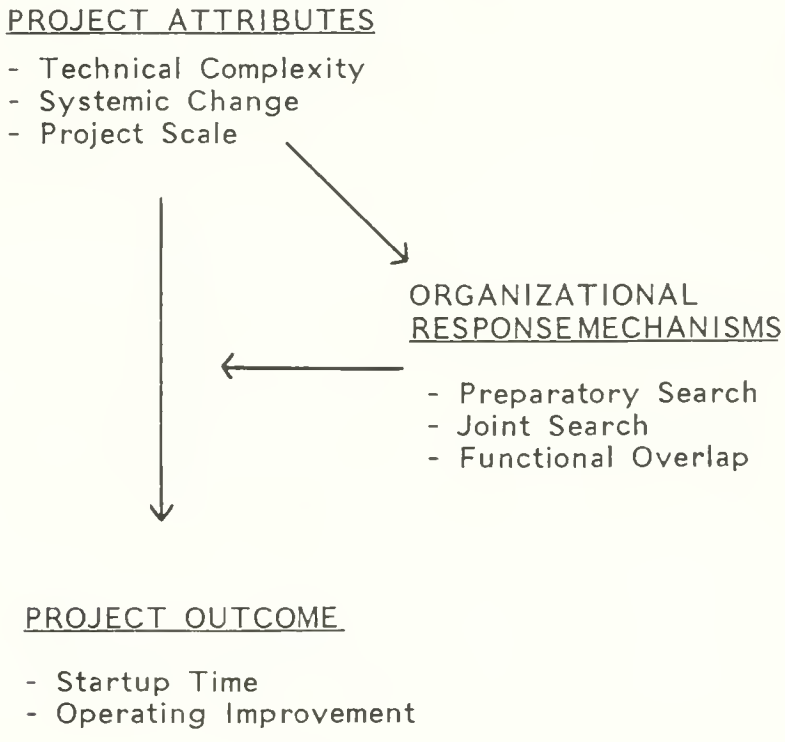
[2] It is important to note that "acceptable" performance does not necessarily correspond to performance at the levels originally targeted for the new process. Rather, it is the level of performance at which managers and project participants agreed that the new process was running as smoothly as existing operations, and the project was considered complete. In some cases performance differed significantly from original expectations.

2. Operating Improvement: Managerial choices are expected to affect the effectiveness of the new technology as well as the efficiency of the introduction process (Leonard-Barton, 1988; Rogers, 1983). Data on improvements in operating performance comes from three interview items concerning the usefulness of the technical solutions implemented, the degree to which technical objectives of the project were met, and the level of operating reliability achieved. The reliability of the aggregate scale is excellent (Cronbach's alpha=.86).

Variables can be organized into an operational model of process change, depicted in Figure 2.

FIGURE 2

Model of Process Change



III. REGIONAL DIFFERENCES

One of the early discoveries in this research was that significant differences existed between the Company's European operations and its U.S. division. These differences are in part the result of managerial decisions and other historical factors within the Company studied. As discussed below, fundamental strategic choices meant that regional operations evolved along different lines, acquired different capabilities and, over time, faced different opportunities.

In addition, it is important to note that these differences developed within particular social and political contexts at the national level. Both specific managerial decisions, and the impact they had on operating units, can be examined within that larger environment. However for the purpose of this paper I shall focus on specific intrafirm comparisons rather than examine their relationship with national or cultural variables.

European Operations

Local managers in the Company's European divisions have a high degree of autonomy over operating decisions. However strategic decisions relating to manufacturing and technology are made by management committees composed of senior managers from division and central staffs. Product line rationalization, as well as process and product development, have been aggressively pursued and centrally coordinated through this vehicle in all European operations since the mid 1960's.

As a result, there has been a coherent strategy for process development in the European divisions for almost 20 years. In the early 1970's the Company's central Process Development Laboratory introduced the first generation of proprietary "ABC" machine tools, which incorporated new concepts for precision metal finishing. European plants soon adopted the technology, completing hundreds of introduction projects. Describing the process, one senior manufacturing manager observed, "It took a long time to debug those early machines and we had many problems. But we learned a huge amount about the equipment, and about how to bring new technology into the plants."

In the late 1970's the Development Lab introduced the second generation of "ABC" machine tools. The new line was based on existing machining concepts but incorporated a proprietary microprocessor control system. This development enabled European plants to introduce one standardized control technology from the start. As a plant manager explained, "We made sure that not one machine was introduced that did not have the possibility to communicate with other machines on the floor."

In the early 1980's the Company's development thrust turned to linking separate machines on the shop floor. The result was the introduction in German and Italian plants of a centrally-controlled, fully integrated machining and assembly system capable of 24-hour low-manned operation. Finally, in the latter 1980's the objective has been to develop flexible integration, where appropriate, for greater market responsiveness in low-volume product types.

United States Operation

Recent history in the Company's U.S. division differs sharply from the above. Until the mid-1980's the U.S. division was operated as a legally separate entity from the parent Company, and pursued a very different set of policies. The result has been the development of a different environment for technological change.

Until 1985 U.S. plants were managed as decentralized, independent profit centers. There was very little product line rationalization or coordination of process development. According to the engineering manager at one U.S. plant, "Until recently, there was no real long-term planning on the subject of manufacturing processes and equipment. Every capital request was reviewed in isolation."

While a number of early examples of internally-developed "ABC" machine tools were introduced in the early 1970's, process investment slowed in later years. When factories did buy new capital equipment they were slow to introduce second-generation microprocessor-based "ABC" machines, relying instead on external equipment vendors and traditional manual technology.

While there were some efforts to integrate separate machining operations, plants often ended up with multiple, incompatible machine control systems. Further, while the German and Italian divisions maintained active equipment development efforts to complement work at the central Development Lab, the U.S. equipment development center was closed in 1972. With that move, many of the functions of the division-level technology group were discontinued.

U.S. factory operations during the 1970's and early 1980's were characterized by fragmented product assortments and low quality levels relative to the Company's standards in its other divisions. During this period, as one division manager described it, "The U.S. division had been making money, but in a short-term mode. They were not investing in technology or productivity."

Comparative data on Company divisions is provided in Figure 3, while data on individual plants is shown in Figure 4.

Figure 3

Comparative Data on Company Divisions

	ITALY	GERMANY	U.S.
SIZE			
Employees	6,128	7,784	3,377
Sales (U.S.$MM)[1]	$550	$400	$150
AVERAGE YEARLY GROWTH IN PRODUCTIVITY, 1970-1985[1]	7%	7%	1.5%
YEAR IN WHICH COMPANY HEADQUARTERS INTRODUCED CENTRALIZED POLICY MAKING	1967	1967	1985
TECHNOLOGY POLICY DETERMINED BY	Company and division management	Company with some division input	pre-1986: plant engineering managers
PRODUCT ASSORTMENT	relatively specialized; range varies by plant	relatively specialized; range varies by plant	fragmented; relatively wide range per plant
PRODUCTION MODE	lines, some batch process	line and batch	batch; some grouped production
DIVISION TECHNOLOGY CENTER	yes; -new equipment design; -plant technical support	yes; -design and build new equipment, -plant technical support	not before 1986; later division tech. unit directs operations improvement program

Figure 3, continued

	ITALY	GERMANY	U.S.
HISTORY OF PROCESS DEVELOPMENT	similar in Italy and Germany; continuous development based on ABC machines and controls since the early 1970's		discontinuous; major effort in 1980's has been the creation of islands of automation
INTRODUCE ABC CONTROLS SYSTEM	late 1970's	late 1970's	mid 1980's; 1-2 in some locations
CURRENT TECHNOLOGY THRUST	develop flexible integrated lines	continue product rationaliztion; integrated line introductions	continue to clean up operations; reorganize production into groups, some lines

[1] Approximate figures

Figure 4

Comparative Data on Factories

	ITALY		GERMANY			U.S.		
	PLANT1	PLANT2	PLANT1	PLANT2	PLANT3	PLANT1	PLANT2	PLANT3
SIZE: NUMBER OF EMPLOYEES	1200	680	850	950	1000	380	150	400
LOCATION setting	rural	rural	industrial town	industrial town	small town	rural	rural	large city
proximity to Division office and tech. center	close	remote	same complex	same complex	remote	long drive	long drive	long drive
PRODUCT ASSORTMENT RANGE	medium	very focused	medium	subcomponents; focused by shop	focused	broad	subcomponents; medium	very broad
PRODUCTION MODE	line and batch	all lines	line, some batch	line and batch	line and batch in separate plants	batch, some groups	batch, some groups	batch, some groups
UNION AND EMPLOYEE RELATIONS[1]	low union particpation; not restrictive, supportive relations		strong workers council imposes some restrictions, generally positive relations		supportive workers council	powerful union imposes some restrictions, but labor relations positive		strong union, relations often not harmonious
RATE OF PROCESS CHANGE, 1982-1987	very high	medium	high	medium-high	high	meduim	low	high
STATISTICAL PROCESS CONTROL[3]	70%	90%	15%	20%	100%	35%	50%	SPC *not applicable
STRENGTHS/ WEAKNESSES[1]	strong technical capabilities, good breadth	sophisticated technical capabilities in focused product/ process area	strong technical group, close to Division technical center	deep knowledge in focused product/ process areas by shop	strong production capabilities in specific product range	strong plant manager, experienced engineering managers, relatively stable production task	small size, low turnover, experienced management and workers	high turnover in management and operators, many changes in production task

NOTES TO FIGURE FOUR

1 From senior managers

2 For the years 1982-1987

3 Coverage of Statistical Process Control as a percent of target; targets are stated in terms of the number of machines for which control charts are generated (Europe) or percent of employees trained in SPC techniques (U.S.)

IV. RESULTS

Project-Level Differences: Project Attributes, Organizational Response, and Project Outcome

Bivariate correlations, shown in Table 1, provide some initial support for the validity of the measures used here. These results suggest that the larger the shift represented by the new technology, in terms of either technical complexity or systemic change, the longer the time required to fully introduce the new technology. On the other hand operating improvement varies only weakly with technical complexity and is unrelated to the level of systemic change. In the absence of other variables, project scale (in terms of dollars invested) is unrelated to the startup time or operating improvement.

Table 1

Relationship Between Characteristics of Technological Change and Project Performance
(n=48)

	PROJECT OUTCOME	
	STARTUP TIME	OPERATING IMPROVEMENT
PROJECT ATTRIBUTES		
TECHNICAL COMPLEXITY	.52**	-.21**
SYSTEMIC CHANGE	.35**	.10
PROJECT SCALE	.07	-.01

Pearson correlations: * = significant at P= .10
** = significant at P= .05

Note that improved performance in terms of startup time is indicated by a change in the negative direction (i.e., shorter startup time) whereas superior operating improvement is indicated by a positive change (i.e., attainment of a higher level of technical performance).

These relationships can be further explored by means of multivariate regression analysis (Table 2). Equations [1] and [3] show that, as indicated above, project attributes by themselves explain a significant amount (33%) of the variation in startup times, but do not explain observed variations in the level of operating improvement achieved.

Considerable insight is gained by introducing measures of organizational response mechanisms into the analysis. Once response mechanisms are included in the regression for startup time (Table 2, equation [2]), the importance of both systemic change and project scale increases considerably. More important, the coefficients of preparatory search, joint search, and functional overlap are all negative; that is, greater use of these mechanisms is associated with shorter startup times. All coefficients are significant (at $p=.05$).

Results of the full regression for operating improvement (equation [4]) also suggest that organizational responses play an important role in successful introductions. Higher level of preparatory search and joint search are both associated with higher ratings of operating performance. The major difference is that the coefficient of functional overlap, while in the expected direction, is not statistically significant.

These results suggest that preparatory search, joint search, and functional overlap are important mechanisms for coping with technological process change. They appear to contribute both to the speed with which manufacturing facilities introduce new process technology, and (with the possible exception of functional overlap)[2] to the degree of operating improvement achieved. It should also be noted that fast startups are, in general, associated with high levels of operating improvement ($r=-.63$; $p<.05$). Therefore, it is not surprising that the response mechanisms identified appear to enhance performance on both measures.

Table 2

Effects of Project Attributes and Response Mechanisms on Project Performance

A. Effect on **STARTUP TIME**

Independent Variables:

	TECHNICAL COMPLEXITY	SYSTEMIC CHANGE	PROJECT SIZE	PREPARATORY SEARCH	JOINT SEARCH	FUNCTIONAL OVERLAP	
1]	.49** (.12)	.32** (.12)	.05 (.12)	--	--	--	R^2=.33 df= 44
2]	.54** (.09)	.74** (.13)	.32** (.11)	-.41** (.09)	-.35** (.10)	-.33** (.14)	R^2=.64 df= 41

B. Effect on **OPERATING IMPROVEMENT**

	TECHNICAL COMPLEXITY	SYSTEMIC CHANGE	PROJECT SIZE	PREPARATORY SEARCH	JOINT SEARCH	FUNCTIONAL OVERLAP	
3]	-.22 (.15)	.12 (.15)	.02 (.15)	--	--	--	R^2=.00 df= 44
4]	-.25* (.13)	-.27 (.18)	-.23 (.16)	.47** (.13)	.30** (.14)	.28 (.20)	R^2=.30 df= 41

Regression coefficients are standardized in order to facilitate comparison of effect sizes.

Estimated standard errors of standardized regression coefficients are shown in parentheses:
** = Coefficient significant at .05 confidence level
* = Coefficient significant at .10 confidence level

Regional Differences: U.S. versus Europe

The U.S. plants in this sample took longer, on average, to introduce new process technology than did European factories and reported lower levels of operating improvement. Table 3 shows summary statistics for the two regions. As noted, no consistent differences were discovered between divisions in Europe.

In order to examine the significance of these differences, a dummy variable indicating the country in which the project took place was included in the regressions for startup time and operating improvement. The effects of the U.S. dummy are shown on Table 4; within Europe, performance effects of individual countries were not statisitically significant.

Table 3

Regional Differences in Means: Europe and the U.S.

	MEAN		STANDARD DEVIATION	
	Europe (n=31)	U.S. (n=17)	Europe	U.S.
Startup Time	19.9	26.9	11.6	17.4
Technical Performance	14.0	10.0	7.4	6.4
Technical Complexity	.02	-.06	.94	.77
Systemic Change	-.05	.11	1.01	.98
Project Size($000,000)	1.52	.50	1.46	.52
Preparatory Search	14.7	12.2	5.6	4.8
Joint Search	10.3	9.1	5.3	4.0
Functional Overlap	2.5	1.3	1.7	1.3

NOTES: Comparative figures are shown to provide a general impression of the differences in scores across regions. T-statistics or other tests of statistical significance are not considered informative, given the relatively small size of the subsamples and the relatively large number of comparisons considered. Differences in means between Germany (n=17) and Italy (n=14) were also examined, however no consistent or significant patterns were revealed.

Table 4
Regional Differences in Startup Time and Operating Improvement

A. Effect on **STARTUP TIME**

Independent Variables:

	TECHNICAL COMPLEXITY	SYSTEMIC CHANGE	PROJECT SIZE	PREP-ARATORY SEARCH	JOINT SEARCH	FUNCTIONAL OVERLAP	U.S. DUMMY	
1]	.50** (.11)	.30** (.11)	.16 (.12)	--	--	--	.30** (.12)	
								R^2=.40 df= 43
2]	.54** (.09)	.69** (.14)	.33** (.07)	-.39** (.09)	-.33** (.10)	-.28* (.15)	.11 (.10)	
								R^2=.64 df= 40

B. Effect on **OPERATING IMPROVEMENT**

	TECHNICAL COMPLEXITY	SYSTEMIC CHANGE	PROJECT SIZE	PREP-ARATORY SEARCH	JOINT SEARCH	FUNCTIONAL OVERLAP	U.S. DUMMY	
3]	-.23 (.14)	.13 (.14)	-.10 (.15)	--	--	--	-.33** (.15)	
								R^2=.10 df= 43
4]	-.25* (.13)	-.20 (.19)	-.25 (.15)	.45** (.13)	.27** (.14)	.20 (.20)	-.16 (.10)	
								R^2=.31 df= 40

Regression coefficients are standardized.
Estimated standard errors of standardized regression coefficients are shown in parentheses:
** = Coefficient significant at .05 confidence level
* = Coefficient significant at .10 confidence level

Equations [1] and [3] show regional differences after controlling for measured project attributes but not controlling for variations in organizations' response to change. On this basis, the U.S. dummy variable is associated with significant decrements in project outcome. Projects undertaken in the U.S. took longer to complete than did projects in European plants by an average of 8.8 plant months, or an increment of almost 45 percent. The "U.S. effect" on operating improvement is comparable; at the mean, new equipment and systems introduced in the U.S. were rated 48 percent below those introduced in Europe in terms of operating improvements achieved.

Once organizational responses are taken into account, however, the association between where projects were undertaken and the outcomes achieved becomes statistically insignificant. The addition of preparatory search, joint search, and functional overlap reduces the effect of the U.S. dummy variable on startup time by approximately two thirds (Equation [2]), and decreases its effect on operating improvement by approximately one half (Equation [4]).

Sources of Regional Differences: Organizational Responses to Change in Europe and the U.S.

This analysis suggests that while the U.S. plants studied do tend to perform poorly on process introductions relative to their European counterparts, a large part of the gap is accounted for by the tendency of project teams in the U.S. to respond somewhat less vigorously to technological change, both before and after the actual installation of the new equipment. This argument is further supported by comparing the relationship between project attributes and organizational response variables across the two regions (Table 5). U.S.-based project teams appear to be less likely than their European counterparts to respond to particularly challenging projects with intensified preparatory search or joint search. In fact, there is a marked tendency to undertake less preparatory search in the face of large-scale projects than in smaller introductions.[3] Further, while the use of functional overlap in U.S.-based projects is strongly associated with the degree of systemic change undertaken, absolute levels of functional overlap in the U.S. are still relatively low. In Europe, six projects rated either five or six on functional overlap (out of a possible high score of 8), while no U.S. project rated higher than four.

Conversely, five projects in the U.S. had an overlap rating of 0 (the lowest possible score), as opposed to one such project in Europe.

Table 5

Organizational Responses to Technological Change

[1] Projects Undertaken in **EUROPEAN PLANTS** (n=31)

	Organizational Response		
Project Attributes	PREPARATORY SEARCH	JOINT SEARCH	FUNCTIONAL OVERLAP
TECHNICAL COMPLEXITY	-.08	.51**	.01
SYSTEMIC CHANGE	.27*	.29*	.39**
PROJECT SCALE	.05	.03	.26*

[2] Projects Undertaken in **U.S. PLANTS** (n=17)

	Organizational Response		
Project Attributes	PREPARATORY SEARCH	JOINT SEARCH	FUNCTIONAL OVERLAP
TECHNICAL COMPLEXITY	-.25	-.11	.31
SYSTEMIC CHANGE	-.15	.27	.62**
PROJECT SCALE	-.56**	.04	.04

Spearman correlations: * = significant at P = .10
** = significant at P = .05

V. ANALYSIS

These results support the notion that managerial differences across regions affect project outcomes, at least in part, through their influence on teams' use of the response mechanisms discussed here. This finding raises important questions about the source of regional differences in search activities and, in turn, in the ability of the plants studied to introduce new manufacturing technologies.

The following analysis seeks an answer in the evolution of manufacturing and process technology within each division. It suggests that different evolutionary patterns created very different attitudes and capabilities in Europe and the U.S. Further, these attitudes and capabilities, once created, proved to be long-lived and resistant to change. Starting in 1985, management at the corporate and division levels began taking vigorous action to address historical weaknesses in U.S. operations. However the evidence suggests that embedded constraints continued to affect efforts to introduce new process technology.

Evolution of Technical Capabilities

As noted in Section II above, both the German and Italian divisions boasted strong installed bases of process technology, excellent manufacturing capabilities, and technically capable personnel which were largely lacking in the Company's United States division. Productivity growth in Europe had averaged 7% per year between 1970 and 1985, whereas the comparable figure in the U.S. was 1.5% (Figure 4). Similarly, while local variations prevent exact comparisons, U.S. plants were judged by Company management to be considerably behind their European counterparts in terms of defect and quality levels, and in measures of operating efficiency such as cycle time and machine set-up time.

Following the introduction of coordinated Company management of U.S. operations in 1985, differences between regions in specific manufacturing performance indicators began to narrow. However, patterns and assumptions developed during the earlier period continued strongly to influence the way in which new process technology was introduced into plants.

Most important appears to be a relatively weak organizational infrastructure for continuous process development and refinement. In the U.S., such activities were not tracked consistently before 1986. According to one senior manager in the region, "There were other ways to show a profit besides worrying about operating efficiencies." The result, according to a

manufacturing engineer who had worked in both European and North American plants, was that;

In America, it's easy to get plant engineers to work on large projects, with formal project management structures, but it's extremely difficult to get attention focused on small projects. People tend to drift away to other problems when the work is only half done, leaving all the little details that actually mean the difference between success and failure in a new piece of equipment.

In both Italy and Germany, plant-level engineers spent a great deal of time developing and achieving annual improvement plans, specified in terms of productivity, quality, and other measures of operating effectiveness. While improvement was managed differently in the two European divisions, plant-level personnel in both countries generally had several process improvement projects ongoing at any time. These "miniprojects" frequently involved iterative development and testing of new tooling or devices in conjunction with the division's local technical center or (especially in Italy) with outside suppliers. According to one senior technical manager;

When we say that European plants are specialized by product line, we mean that they concentrate not just on making those parts but are also responsible for both product and process development. Each division is a development center for a specific technology. Underlying this is a strong requirement -- and will -- to improve on what now exists. While we rationalize product lines, we integrate technical ideas across plants and across divisions.

A closely related difference between the two regions concerns the way in which project teams used external sources of expertise, both inside the company and outside it, to explore technical problems and potential solutions. While counterexamples exist, U.S. project teams tended to expect to purchase solutions from equipment vendors or component suppliers, whereas project teams in Europe were more apt to use outsiders as a resource for continued development of a given item. This contrast is apparent in the way project teams in the different regions viewed the development of new tooling to support new process technology. In Europe, tooling development typically was viewed as a critical task requiring the combined knowledge of both plant-level engineers and tooling experts from internal and external suppliers. For instance, one project leader in an Italian plant explained that;

We identified very early what would be the most critical problem to solve: developing tooling of sufficient precision to allow us to take advantage of the new CNC technology. And we devoted a great deal of effort to a thorough tooling study. An important part of this process was working with the tooling experts at the equipment developer -- the real workers who use those machines -- to understand how to utilize this new technology.

Developing tooling systems which were not just usable but optimal was considered one of the factory's regular responsibilities, and was a focus of attention before, during, and after the introduction itself. In several instances, this emphasis blurred the exact boundaries of the introduction "project" itself. As one German project leader told me, "You really can't call all the continued effort at tool optimization part of the project -- that's something we are always doing, on all our equipment."

In contrast, many U.S. project managers expressed the view that the most efficient approach was simply to purchase a satisfactory tooling package from the equipment vendor, thereby avoiding the need to invest time in tooling development. One manager attributed the problems which plagued a particular introduction to the fact that the machine had not been purchased along with a full complement of tooling from the vendor. Another project manager explained that the external supplier had delivered a tool set "which worked right off the bat. It never presented a problem, so we never had to run any more trials or ask for changes." He was extremely satisfied with the arrangement.

The notion that technology can be purchased "off the shelf" extended to new manufacturing equipment from the Company's Process Development Lab. As a senior U.S. manufacturing engineer explained;

The new machines from Central Lab require a shift in skills and operating procedures -- but that is all provided. You don't need to have all the knowledge in place because the machines come complete with hardware and software, reference manuals, and service engineers from Central to do the training and initial set-up. Once you learn how to push the buttons, these machines are quite simple to use.

This expectation, however, was not borne out in practice. In almost every instance where equipment from the central Lab was introduced into a U.S. plant, project participants complained that the machine did not in fact operate

according to specifications, and that the service engineers who performed initial set up did not complete the task of debugging the equipment or training local operators. Engineers from the Process Development Lab, in turn, argued that U.S. managers and technical personnel expected Lab engineers to run their equipment for them. While there were notable instances in which U.S. project participants invested heavily in joint search with equipment vendors, all but one such case involved vendors external to the company and technical features which were relatively well-developed (low to medium technical complexity).

While European project participants also complained about technical support from the central Lab, they simultaneously stressed that part of the development responsibility must rest with the factory. As a divisional manager explained;

Engineers in the Labs are experts in the machine technology, but we are the ones who really understand the manufacturing process. Therefore, to take a machine which meets the basic specs and make it respond to all our requirements --that's the job of the factory.

Engineering Infrastructure:

The different attitudes and capabilities displayed in Europe and the United States appeared to be rooted in different engineering "infrastructures" in the two regions -- that is, in contrasting approaches to the organization and development of technical talent in the manufacturing environment. Although Germany and Italy differed in many details of their engineering infrastructures, both divisions shared common themes which were absent in the U.S.

1. Italy: In Italy, according to the division's director of manufacturing technology;

The word "engineer" is hard for us to define. There are at least two possibilities this can refer to within the plant. First and foremost, the backbone of this organization is the "shop floor engineer". He is in the line: generally a foreman or assistant foreman. He is responsible for production and quality, as well as for cost and quality improvements. He also has hands-on responsibility for new projects. Second, there are factory technical offices. These are the future-oriented engineers; they support production people in ongoing operations but they also develop new kinds of solutions. But they never have direct project responsibility for new process introductions. It's

important that line managers have responsibility for new technology from the start.

Indeed, in many instances it was difficult to measure the degree of functional overlap in Italian projects because respondents sometimes had trouble distinguishing engineering and production as separate functions. In several cases, an individual was described as having direct responsibility for manufacturing, but also maintaining a seat in the plant technical office.

Personnel development in the Italian division includes considerable job rotation between direct manufacturing supervision and the plant technical office. All levels of manufacturing management and technical experts go through a "spiral of rotation" which begins with machine attendance and generally includes experience in a variety of manufacturing and project situations. Promising individuals also move between the division technical center and the factories. While the Italian technical center itself is very small, its staff works closely with plants to understand their needs, and with outside machine shops or component suppliers to realize new ideas for machines or devices for use in the plants. In addition, people move between plants over the course of their career, creating a basis for sharing knowledge and experience among plants in the division. The Italian division was noted for its ability to utilize and build on existing knowledge through extensive in-house training, team structures for almost all activities, and cross-fertilization among areas and plants.

Many observers within the Company pointed to the deep capabilities developed by this system at the level of production setters, supervisors, mechanics and maintenance people. As the Company's director of manufacturing described it;

Our Italian plants put less emphasis on the pure engineering excellence of their people than do, say, the Germans; but their strength is in the very careful, conscious management of their technology. They have created a very high level of interest and ability among **all** their people.

The outcome, as one U.S. engineering manager remarked, was that;

The Italians are wonderful at making all kinds of process refinements--and it's because of the management there, not the product line or anything

else. They love to "fiddle" with their equipment. But it's not a game --they are very conscientious about applying their knowledge to their operations. You take a machine which we consider great, but they make lots of little innovations and end up running twice as much product on it.

2. Germany: In the German division, the plant-level engineer is conceived quite differently. Engineering is organizationally distinct from production management and generally reports directly to the plant management. Many plant-level engineers have formal engineering degrees, as distinct from the apprenticeship undertaken by operating personnel. Indeed, there are important distinctions within the engineering office based on individuals' formal technical training.

In theory, at least, responsibilities in the plant are clearly bifurcated. Engineers are directly responsible for cost and quality improvements. The chief engineer is the formal project leader for planning and administration of new process introductions, and implementation is generally the direct responsibility of a process engineer in his or her group. Production managers, meanwhile, are responsible for meeting output targets in terms of quality and quantity. They are also expected to support the engineers' improvement efforts, principally by allocating people and development time to improvement and introduction projects.

However, these clear distinctions often break down -- or are actively broken down -- in practice. Two of the three plants studied in Germany presented exceptions to the standard organization structure. One plant was composed of several small shops or subfactories; within them, engineers reported to manufacturing shop managers. In fact, in at least one of these shops, the production manager was also the chief engineer. In another plant, in addition to the "real" (degreed) engineers working in the technical office, there were also engineers who "sat on the production floor" in each department and reported to manufacturing managers.

Further, there was considerable technical expertise among production personnel at all levels. Production managers typically were shown considerable respect by degreed engineers on the basis of their technical know-how. As one degreed engineer explained, "The manufacturing supervisor and the department manager are really engineers too -- they are the floor engineers." While their

technical capabilities varied, manufacturing managers at this level all received some formal technical training, and they were the first ones to respond to technical problems on the line. Indeed production department managers frequently came from the plant's engineering office. In many cases, junior engineers in charge of introduction projects reported in a sort of informal matrix arrangement to the production department manager.

Relative to Italy, technical personnel in Germany were less likely to rotate among plants or between plants and the division technical office. On the other hand, considerable efforts were made to link technical development activities at various facilities. First, five of the seven plants in the division were located in a geographically centralized "complex" along with the division headquarters and technical center. The division technical staff, which was several times the size of the group in Italy, was responsible for designing, building, and helping plants to implement new equipment and systems. Especially in plants located in the central complex, there was considerable interplay between plant engineers and engineers at the technical center. Further, factory personnel with particular areas of expertise or experience were often consulted or even borrowed for projects undertaken in other plants in the complex.

Whereas Italy was known within the Company for its penchant for "fiddling" with production equipment once it was on the floor, Germany was famous for doing a great deal of technical preparation of both the new equipment and the existing factory before attempting a new introduction. While this did not always occur (as measured by levels of preparatory search in the projects studied) it consistently was recognized as being of utmost importance. One project leader explained;

> This was one of our most successful introductions because we worked explicitly to identify all the most important unknowns, and to develop solutions, **before** the equipment was shipped or, in many items, even before it was ordered. If you really think about it, you can identify and address 95 percent of the hard issues beforehand.

3. United States: The formal organization structures of U.S. factories resembled the German pattern, with separate engineering departments reporting to the plant manager. However, with the exception of the small subcomponent plant

studied, informal integration of technical priorities and production requirements was often more difficult to attain. In several instances, plant-level engineers blamed delays in introducing new equipment on the difficulty of getting the production manager to set aside time for operator and supervisor training or for on-line testing of tooling or devices. Manufacturing managers, meanwhile, frequently attributed disruption and startup delays to the absence of engineering support during startup and later debugging of the new equipment.

Further, many individuals in the company argued that engineering capabilities in U.S. plants were too thin. In the U.S., formal and in-house technical training or personnel development through job rotation received much less attention than was true in Europe. Plant-level engineering capabilities, and the relationship between engineers and production people in the plants, varied widely. Unlike the situation in European divisions, high turnover among engineers was a frequently-cited problem. As one senior manager said with dismay, "Many of the engineers in these plants are not even from our industry. They do not <u>really</u> understand the products and processes involved."

In addition, managers and technicians on the plant floor often lacked necessary technical skills. According to one European engineer who had worked in various U.S. operations;

> The production supervisor is the place where there is very often a big gap. In too many cases, the supervisor does not have sufficient understanding of modern production technologies, so he ends up relying of operating people for process expertise. Sometimes the operators have long experience and special aptitudes, but sometimes that is not the case. So it can be hard to carry out big projects successfully.

Another engineer, who had worked in the Company's U.S. division for some forty years, pointed to serious erosion of process capabilities among the "engineering backup" in local factories. In his view,

> The operator level is not, or should not be, what is critical. Productivity of both old and new machines comes from the engineering backup in the plants -- the engineers, maintenance people, and supervisors. That small group has got to be the organizational intelligence between management and operators. They have to be able to teach operating people, to guide them to focus on key problems, not just rely on operators' expertise. The competence of that group and how it is cultivated is the key to the ability to bring in new machine technology.

VI. CONCLUSIONS

This paper has analyzed the performance of new process introduction efforts undertaken within a single technology-based company operating in both Europe and the United States. The analysis has suggested that regional differences in performance can be traced to underlying differences in the way project teams respond to technological change. The response mechanisms identified -- preparatory search, joint search, and functional overlap -- were shown to support improved project performance in terms of startup time and operating improvement. However, it was also shown that project teams in Europe and the U.S. differ in their propensity to use these mechanisms in dealing with challenging introductions.

I have suggested that these response patterns may be linked to historical choices concerning the development of technology in the operations studied. This study identified three critical and related areas of managerial choice governing the development of technical capabilities in manufacturing. First was the existence of a multi-faceted, strategy-level management body charged with the guidance of process development activities. In Europe, this body served to coordinate development efforts over time, among plants, and between plants and internal R&D facilities. Second was a consistent, top-to-bottom emphasis on the continuous improvement of existing manufacturing processes. This effort showed up plainly in high levels of productivity improvement and quality performance in European divisions, and in the attitudes and assumptions which project participants brought to new process introductions. Finally, the third area of managerial choice which differed across regions was the creation of a system for building technical competence in the manufacturing organization. In Italy in particular, continuous managerial emphasis on training, cross-training, and cross-fertilization appeared to have resulted in a workforce which brought unusual capabilities to both ongoing process improvement and new process introductions.

This paper leaves many questions unanswered, and perhaps suggests some new ones. First, it must be remembered that this study was confined to a single company. No attempt has been made explicitly to link managerial choices in the company's different operating units to broader political, economic, and cultural forces in Europe and the U.S. Therefore it is impossible to generalize these findings to other organizations in the countries involved. On the other hand, the findings reviewed in this paper are broadly consistent with conclusions reached by other authors who have compared the development of manufacturing technology in different national contexts, including Jaikumar (1985), Hayes and Wheelwright (1984), and Piore and Sabel (1984).

More important this study suggests that a company's strategic guidance of its manufacturing technology, and its attention to the long-term development of people and processes, are intimately linked to its ability to utilize new manufacturing technologies. This interdependence has been suggested by analysts and industry observers (e.g. Schonberger, 1986; Manufacturing Studies Board, 1986; Thurow, 1987), however there has been little empirical evidence to support assertions[3] and little clinical detail on the effects of different managerial choices in these areas. I have tried in this paper to show how historical choices about technology influence not only a firm's current standing but also its ability to redefine itself through the introduction of new technologies.

More research is merited which explores these connections within the global corporation. The questions involved are important for increasing our understanding of the process of technological change in manufacturing organizations. Further, these issues are of vital practical concern in light of the serious questions which now surround the global competitiveness of the U.S. manufacturing sector.

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[3] An important exception to this is work by Hayes and Clark (1985) and their colleagues, who showed that plants which were "better managed" in terms of quality performance and inventory levels were also able consistently to introduce new equipment with less disruption than more "poorly managed" plants.

1. This research tradition is represented by two streams of research. First, much of the "implementation" research published during the 1970's examined the different requirements of various stages in the innovation process. Many authors concluded that implementation, as distinct from development, calls for relatively tight forms of managerial control (Duncan, 1976; Sapolsky, 1967; Zaltman, 1973). Another research stream focuses on creating organizational or worker receptivity to the new technology (Coch and French, 1948; Majchrzak, 1988; Nutt, 1986).

2. It is worth noting that the ambiguity surrounding the role of functional overlap is explained by examining its effect given different kinds of technological process change. As discussed in Tyre (1988), functional overlap appears to be an important mechanism for responding to high levels of systemic change. However, evidence suggests that functional overlap is not important for dealing with technical complexity in new process introductions.

3. One reason for this surprising finding is that, in many cases, large-dollar projects involved the introduction of new equipment from the Company's central Process Development Lab. U.S. project managers frequently expressed the belief that it was "their responsibility" to fully test their equipment and to deliver working production machines. This issue is discussed later in the paper.

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